

UNDERSTANDING NEW-AGE USE OF “NANO”-MODIFICATIONS IN ROAD PAVEMENT DESIGN AND CONSTRUCTION (Paper under preparation)

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The following facts with regard to the “nano”-Modification of Bitumen Emulsions in road pavement design and construction are based of scientific proven concepts:

1. The normal main argument is usually centred around the use of so-called “Untested Technology” – an argument that in itself is not correct. The mere fact that “nano” may be perceived as a new “buzz” word does not mean the technology is neither new nor untested. The use of “nano”- technology is nothing new in the Built Environment and dates back to the 1860s in Europe when Scientist were tasked to develop protective additives for stone buildings, monuments and statues to protect them from the detrimental effects of climate and pollution. These additives were identified in the 1980s as “Nano” products when technology progressed to a stage where scientists were able to actually see atom size particles and molecules and identify the molecular interaction between the developed protective agents and the attachment between the minerals comprising the “stone” buildings, monuments and statues. At this stage already, the type of mineral in the stone was identified as a key element in the effective adhesion of some of the protective developed “Nano” products. These “Nano” products are currently used all over Europe as protective agents to protect “low-cost” houses, buildings and monuments comprising various basic mineral types. In the road industry these “Nano” products are generally referred to as “Stone” or “Aggregate Adhesives” – records in road construction of the use of such “adhesive additives” dates back more than 20 years. It should be emphasised that due to the basic scientific nature of the atom and molecule interactions between basic minerals forming the basis of ALL rock types in the crust of the Earth, the action of these “nano” products are independent of climatic effects.
2. In the road building industry Bitumen–Emulsions were introduced into South Africa in the 1960s. The South African Buro of Standards (SABS) document **SANS 4001-BT3 – Volume 1 – “Civil engineering specifications: Part BT3: Anionic bitumen road emulsion”** was only published in 2014 (Volume 1) (More than 50 years after the use of Anionic Bitumen-Emulsions have become common practice in the South African Roads industry.) In this document Bitumen-Emulsion is defined as containing only: “bitumen, emulsifying agent(s), and water.” **It is important to note that NO test or specifications with regard to the properties of the “Emulsifying Agent(s)” are prescribed, given or available within the SABS specifications.** It is a fact that various “Emulsifying agents” are used by the various Bitumen-Emulsion manufacturers, which have a known difference in stability (known by the manufacturers – not common knowledge among engineers – in fact very few engineers know anything about “emulsifying agents”) that could result in considerable differences in behaviour when used as a stabilising agent in road construction. Very few pavement/material engineers specify the type of “Emulsifying agent” to be used in the production of Bitumen-Emulsion for road construction purposes. Bitumen-emulsion

produced with a “less effective” “Emulsifying Agent” could result in the separation of the bitumen and water if used some distance from the manufacturing plant or instability and dramatic and costly failures when used in road construction under certain unfavourable conditions. **All of these “Emulsifying Agents” are, in fact, “Nano”- products or particles** known as “Janus”- particles (from the Greek Mythology - translated as two-faced) with a tail embedded in the bitumen molecule (this “attachment” part differs from product to product and is controlling the behaviour of the “nano” particle) and a “head” attracting water molecules. Hence, this “Nano”- particle or “Emulsifying agent” enables the mixture with water and bitumen “oil”). It follows that:

- a. No SANS document for the specification or testing of these “Nano”-particles exists – if fact it is certain that maybe except for a few chemists working with Bitumen-Emulsion manufactures nobody would be aware that the “Emulsifying agent(s)” are in fact “Nano”-technology that is applied in producing a stabilising agent for general use in pavement engineering – in the field of pavement engineering this fact would be unknown except to the few engineers/technologist/technicians that have attended some of my training courses or the collection of PhD qualified pavement/materials engineers participating in the SANRAL research programme which intended to build test sections using Bitumen-Emulsion as a stabilising agent and had to be made aware of the fact that not all Anionic Bitumen-Emulsions are the same due to considerable differences in the “Emulsifying Agent” (“Nano”-particle) used.
 - b. It should be noted that the “Nano”-technology used in the manufacturing of Bitumen-Emulsion is **totally independent from CLIMATIC CONDITIONS and is a chemical process enabling the binding and mixing of Bitumen (oil) with water.** These are facts not well known or understood in the road building fraternity.
3. The “Nano”-modifications to Bitumen-Emulsions researched in close corporation between the GPDRT with the Civil Engineering Department of the University of Pretoria (that is currently rated among the top 0.1% in the World and more than 200 places above any other Civil Engineering Department at Universities in South Africa) (and together with the CSIR and other Universities in Gauteng is in the process of establishing a Centre of Excellence in line with the policy of the MEC of Transportation in Gauteng) are similar to the “Nano”-technology (“Emulsifying agents”) used in the formation of Bitumen-Emulsions. Normal Bitumen-Emulsions consisting of Bitumen molecules (± 5000 nano-metres (nm) in size and Water molecules ($\pm 10^{-4}$ nm in size) both have relative high surface tension characteristics and due to the effect of “Van der Waal” forces form visible droplets (measured in millimetres) consisting of a considerable number of Bitumen molecules. The introduction of a second “Nano” –particle (Alkyl-Alkoxy silane/silanol/siloxane, etc.) with a considerable lower surface tension and viscosity (scientific facts) at the correct “shear force” (scientific fact) results in the separation of the Bitumen molecules in the droplets, resulting in a “Nano-Modified Bitumen-Emulsion” (referred to as NME – SATC17 paper) stabilising agent with a considerably improved distribution characteristics due to the smaller “droplets” of the “Nano”-Modified Bitumen-Emulsion (scientific proven fact). Hence, much more

effectively distribution of the “Nano”-Modified Bitumen-Emulsion can be achieved within any soil/aggregate/stone/clay that is to be stabilised. **This addition and effect of the “Nano”-Modified Bitumen-Emulsion is independent on ANY Climatic effect and similar to “Emulsifying Agents” that have been in use for more than 50 years.** IT is emphasised: NO SABS specification or test procedure exists to tests these Nano-products. These products are produced under strict international standards under ISO 9001 and ISO 14001 specifications – of which **NO SABS equivalent exists**. Similar to “Nano” “Emulsifying Agents” these nano-products have a “tail” that firmly embeds itself in the Bitumen molecule with a “head” design to attach to a specific minerals in the soil/aggregate/stone/clay to be stabilised (bound together). These bonds between the “Nano”-modified Bitumen-Emulsions and the minerals present in the soil/aggregate/ stone/clay (Si-O-Si, Si-O=C, etc. depending on the minerals) are among the strongest bonds commonly found in nature. At the same time, these “Nano”-modified Bitumen-Emulsion bonds effectively repel water-molecules and protect the minerals in the sand/aggregate/stone/clay from contact with water-molecules. A pre-requisite for mineral decomposition is the presence of water molecules (Weinert, 1980). Through effectively sealing the minerals from contact with water-molecules further weathering of the minerals is prevented. **These interactions as described are scientific facts based on basic chemistry and irrefutable - not influences by climatic conditions.** However, sand/aggregate/stone/clay mineral content is the result of weathering due to climatic conditions and is fundamental and a very important part of identifying the correct and effective “Nano”-modification to the Bitumen-Emulsion to be added in order to obtain the optimum resets.

4. Researchers the University of Pretoria realised that the traditionally used empirically derived material tests (mostly dating back more than 50 years) used in the road building industry is totally inadequate to effectively identify the minerals present in available materials to ensure strong bonds between the stabilising agent (Bitumen-Emulsion) and the material to be stabilised. Modern cost-effective technology (X-Ray diffraction (XRD) scans of sand/aggregate/stone/clay) has been available for more than 40 years. XRD-scans give an accurate composition of the different minerals in the road building materials to be used. Hence, XRD-scans of the material were introduced as a pre-requisite for the effective design using “Nano”-Modified Bitumen-Emulsions as a stabilising agent. Test protocols were written (copy right preserved - Prof Jordaan) to not only determine the main minerals present in the road building materials, but also to determine the decomposition that has taken place under the specific climatic conditions, enabling the neutralisation of any “Problem” minerals that may have developed as a result of different climatic condition. **Hence, the argument that “new nano-technologies” used in the modification of Bitumen-Emulsion have not be tested under local climatic conditions are null and void** and can only be uttered as an argument resulting from ignorance with regard to the technology and the procedures developed at the University of Pretoria to scientifically analyse the materials (determined the minerals) and effectively apply this technology in practice taking into account all climatic and weathering conditions.
5. It is important to note that the stabilising agent used is still **BITUMEN-EMULSION**. Due to the “Nano”- Modifications to the Bitumen-Emulsion, much smaller quantities of the stabilising

agent can now effectively be distributed in the material to be stabilised at much better adhesion and much less cost. Due to the fact that “problem minerals” are identified during the design stage (mineral analysis of the materials) the use of “Nano”- Modified Bitumen-Emulsions (NME) also enables the use of naturally available road building materials instead of very costly scarce newly crushed stone.

6. The “Agrément” – certification process developed by industry (not an official (authority) introduced certification process) has serious scientific-based short-comings with regard to the fundamental material science described in the preceding discussions and would require a firm scientific base to gain any credibility in a modern scientific environment. Certification based on the testing of products based on a “sand” and “sand containing 30 per cent clay containing Smectite” with **no** scientific data available of what is been tested does not pass the scrutiny of any scientifically based certification process. Sand can vary from containing 100% silica (Si) to 100% Calcium (Ca) while sand containing 30 per cent “clay” containing Smectite is a vague description of a material dating back to the very archaic test procedures previously mentioned.
7. “Agrément” is neither suitable nor applicable for the testing of “Nano”-Modified Bitumen-Emulsions. Any argument of the opposite may just as well suggest that it is suitable to test the various “Emulsifying Agents” using the “Agrément” certification process. The mentioned shortcomings in “Agrément” certifications are the very reason why this industry-led certification process is not accepted by some major role players and producers of Bitumen-Emulsions (these producers employ chemists with a good understanding of chemical compositions and interactions and the benefit of modifications). Numerous modified agents have been introduced to improve existing Bitumen products over the last few decades without “Agrément” certification by the Bitumen manufacturers with considerable benefits to the industry.
8. Over and above the applicability of “Agrément”-certification it is questionable whether this industry-led certification process will pass the scrutiny of the Competition Act, Act 89 of 1998 where it is clearly stated in the Pre-Amble to the Act that it aims to, inter alia, prohibits and “restrain particular trade practices which undermine a competitive economy” and to “provide for markets in which consumers have access to, and can freely select, the quality and variety of *goods and services* they desire”, etc.
9. The introduction of scientific based tests in the analysis of the materials used for the rehabilitation of the Tswinga-Muledane road in Thohoyandou in 2015 made it possible to use the in-situ G7 material and modified it with 0.7% NME to form a new base-course. This road carried traffic on the exposed base layer over the December/January period with high rain-falls recorded without deterioration before being over-laid. Similarly, the on-going construction of the K46 (William Nicol) made this the first road in Gauteng to be constructed taking into account the actual minerals present in the materials in the design of a suitable stabilising agent. As a result of the tests the relatively high Mica contents was scientifically determined and the site laboratory informed (the presence thereof was initially denied in defiance of scientific proof and two weeks later admitted when tests with cement (as per

original design) showed that neither the required densities and tensile strengths could be obtained in the laboratory). Tests with an appropriated “Nano”-Modified Anionic Bitumen-Emulsion on the K46 passed all required test results by considerable margins using any available acceptable strength criteria prescribed and accepted in industry for Bitumen-Emulsion stabilised materials. Hundreds of tests conducted as part of the quality control on site during the construction of the road pavement layers since 2016 showed “unheard” of high tensile strengths (ITS) (important due to the fact that these layers are in tension when subject to loading) and passed the Unconfined Compressive Tests (UCS) and density tests generally with ease. In cases where problems did occur (very few), the origin of the problems was identified as unrelated to the “Nano”-Modified Bitumen-Emulsion. As a result of the quality control tests there can be no argument about the bearing capacity the specific layers that have been approved by the Engineer, irrespective whether the layers are defined as a Bituminous Stabilised Materials (BSM) (considered not to be specific enough with such designs generally containing cement) or the more appropriate NME (“Nano”-Modified Emulsion with no cement additive required due to the water-repellent nature of the modification) classification. Any argument to the contrary shows little understanding of the technology used and the considerable positive impact it could have on the cost-effective delivery of road infrastructure, enabling the general use of naturally available road building materials instead negating the buying of material from commercial quarries with limited access in large parts of the country resulting in greatly increased costs due to long haulage distances. The water-resistance nature of the NME modified G5 material used in the base of the K46 was proven in February/march of 2017 when more than 200 mm of rain in a period of one week caused no damage to the completed and exposed (not even a prime) layer. Any high quality granular layer such as a G1 would, under similar conditions, have required reconstruction.

10. The alternative surfacing designed for the Thohoyandou, K46 and similar roads with an Ultra Violet protection and FT-wax (Sasobit) modification may be the first surfacing designed for roads in South Africa with a crack-free life not requiring a reseal to protect the pavement structure from water ingress during the design period.
11. The Heavy Vehicle Simulator (HVS) test sections (4 tests for 4 different design traffic loading classes) recommended on road sections constructed with NME technology **have not been proposed to test the technology** – that has been proven all over the world (with a sound scientific base (irrefutable)), also under climatic and weathering conditions similar to South Africa (refer Weinert. 1980 and areas where the technology is being used with millions of tons of “Nano”-Modified Bitumen products being produced on an annual basis) - but to demonstrate designs for different traffic loading and to further optimise analysis procedures. The analysis procedures used for the design of the P249, K46 and other roads and pavement structure is based on Bitumen-Emulsion Treated Materials (refer DOT documents refereed papers) without the considerable benefits of the “Nano”-modifications and contains a “safety factor of between 4 and 5 (refer design documents)”, making the designs “conservative” in terms of bearing capacity. Considerable additional savings could be achieved through the approval and implementation of the original HVS proposal compiled in co-operation with the University of Pretoria, the GPDRT and the CSIR.

12. Pavement designs generally produced are still based on design catalogues, compiled based on technology developed in the 1980s with little cognisance of the properties of the available in-situ materials and naturally available materials in the area that could cost-effectively be used in the construction of roads. This approach is generally enforced with **little** understanding of the cost implications of the design decisions or of the fact that the surfacings that are being specified do not even consider modern available Bitumen modifications that would considerably lengthen the crack and deformation characteristics of the bituminous binders which would result in considerable savings. The mentality among “traditional “engineers to relying solely on empirical test results dating back more than 50 years, often lead to costly failures with no understanding of the fundamental mineral composition and reaction with stabilising agents of the materials or, result in considerable excessive designs not considering scientifically measurements and not using cost-effective available materials. This “bulldog” approach deprive millions of citizens of basic road transport facilities, wasting billions of taxpayers’ money that could be applied to provide much more road for less cost by effectively using modern available tests and materials.

13. The University of Pretoria is currently the only academic reputable institute in South Africa that have any Engineering Knowledge and Experience of the modifications to Bitumen Emulsions using “Nano”-technology. Not only did this research entailed a thorough investigation into the basic science (chemistry and physics) involved in the “Nano”-technologies, but numerous of tests on numerous different materials with numerous different “Nano” additives have been conducted over the last couple of years, introducing for the first time minerology tests as a basis for the understanding of the technology and the considerable benefits that could be achieved by using the technology correctly.

Finally, in my experience (almost 40 years), it should be noted that the changing of a design after the award of a project is not unusual and numerous examples exist where contractors proposed alternatives which have been deemed advantageous to the project, the road construction fraternity, the authority and the road user as the tax-payer.